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Feasibility of peer-to-peer energy trading in low voltage electrical distribution networks

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Abstract

Peer-to-peer (P2P) energy trading is referred to as flexible energy trades between peers, where the excessive energy from many small-scale Distributed Energy Resources (DERs) including those in dwellings, offices, factories, etc., is traded among local customers. To assess the feasibility of P2P energy trading, where local electricity demand and supply balancing is desired, a so-called P2P index was developed. By clustering the historical smart metering data using the *k*-means method, customers were categorized by their electricity consumption patterns and representative demand profiles of low voltage electrical distribution networks were produced. A linear programming optimization was carried out to find the optimal capacity of different DERs to maximize the local demand and supply balancing. PV systems and combined heat and power units were considered as the renewable resources. This work provides network planners with guidelines of appropriate shares of DERs for better constructing their future networks, and facilitates a P2P energy trading market paradigm.

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Keywords: Peer-to-Peer energy trading, demand and supply balance, PV system, Combine Heat and Power, optimization

1. Introduction

Existing electrical energy systems were designed and built to accommodate large-scale generating plants, with demand traditionally considered as uncontrollable and inflexible, and with centrally controlled operation and management. Recently, there has been a revival of interest in connecting Distributed Energy Resources (DERs) to distribution networks, and microgeneration and flexible loads at the premises of end users. DERs suffer from the issues of uncertain availability due to varying weather conditions. Flexible loads are not currently utilized for balancing local generation. Thus, a challenge for the Distribution System Operators (DSOs) to provide a secure network to meet peak demand, and to

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move to more active DSO roles with new business models, is increasingly critical. However the current changes cannot be effectively implemented within the existing technical schemes and market frameworks, and may result in a degradation of economic and environmental performance. There is a vital challenge to the DSOs, and new business models are essentials for their survival under this energy revolution.

A large penetration of DERs also creates operational problems in distribution networks. For effective operation of the distribution networks, different approaches are being considered. One approach would be to break the network into smaller entities such as Microgrids and CELLs [1]. These investigations of Microgrids, CELLs, etc. were mainly focused on the technical issues. However the challenges that DSOs are facing with the energy revolution were not fully addressed. Radical decentralised systems and regional market solutions are clearly required to bring the end users and DSOs at the heart of system operation, and to provide effective technical and new market arrangement and business models for DSOs.

Peer-to-Peer (P2P) energy trading might be a way forward to provide these market and technical solutions. P2P energy trading is defined as flexible energy trades between peers, where the excessive energy from many small-scale DERs is traded among local customers. Recently, some work has already been carried out on the P2P concept of trading local energy resources with other customers. Several projects, such as “Piclo” in the UK [2], “Vandebron” in Netherland [3], and “SonnonCommunity” in Germany [4] each proposed a possible business model for P2P energy trading considering from suppliers' perspective. However, it would be necessary to assess the portfolios of these renewable resources as well as the electricity consumptions and to evaluate the feasibility of balancing them.

2. Peer-to-Peer Energy Trading

The P2P approach promotes regional energy trading and demand response to available resources in local areas, and this increases the efficiency, flexibility and responsiveness of local resources. Due to the hierarchical nature of the distribution networks, the P2P energy trading will be carried out in three levels: Level 1: P2P within a Microgrid; Level 2: P2P within a CELL (multi-Microgrids); and Level 3: P2P among CELLs (Multi-CELLs), as shown in Figure 1. In Level 1, each customer (normally in an low voltage (LV) network) is considered as a peer, in Level 2 each Microgrid is a peer (Level 2 is normally a medium voltage (MV) distribution network), and each CELL from Level 2 is a peer in Level 3.

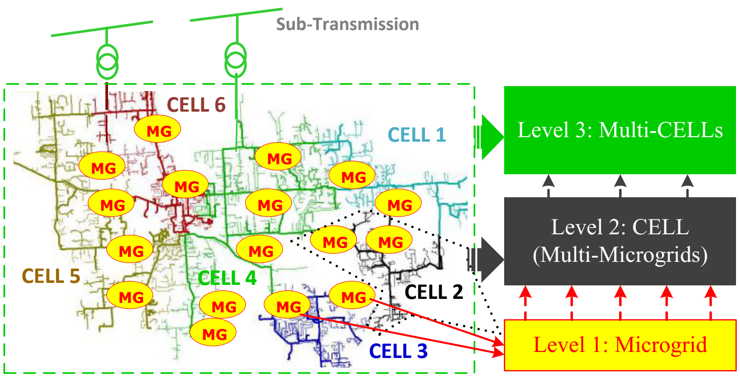

Fig. 1. Structure of peer-to-peer energy trading

3. Clustering Customer Demand

In the UK, a number of generic profile classes (PCs) are provided by Elexon for residential, commercial and industrial customers, and are derived based on the average of all customers contained within a single PC [5]. Although these PCs are suitable for settlement, in reality they are not reflective of how electricity is actually consumed within the home. Individual households may use electricity in very different ways [6]. Cluster analysis is able to group customers which have a similar electricity use pattern and this obtains better knowledge of the network demands than a simple aggregation. This can be used to produce representative demand profiles of distribution networks. A better planning of the DERs is therefore able to be carried out for the P2P energy trading.

3.1. Methodology to produce representative demand profiles

The process to producing a representative demand profile is divided into four stages (see Figure 2).

3.1.1. Stage 1: Segmenting data

The smart metering data is segmented on a daily basis (from 00:00 to 00:00 next day) with a 15-min resolution. For a data set of *n* customer for a period of *M* days, there are a total number of $n \times M$ daily load profiles. These daily profiles are the input of the k-means clustering analysis.

3.1.2. Stage 2: clustering analysis using k-means method

The k-means method is used to cluster these daily load profiles. Each of the daily load profiles produced in Stage 1 is classified into one of the PC groups, and each PC group is one cluster.

3.1.3. Stage 3: Customer profile class classification

Usually customers use electricity differently on a daily basis, and thus multiple PCs over a period were found for some customers. The PC, conform to which a customer used for the majority of the time across the analyzed period (i.e. *M* days), is considered for that customer.

3.1.4. Stage 4: Creating representative profiles

A representative demand profile is an aggregation of randomly selected profiles from PC pools. Each of the PC pools is consisted of the members of the corresponding PC obtained by using k-means method. The proposition of different PCs is determined either by the nature of an existing LV network or user defined depending on the purposes of research.

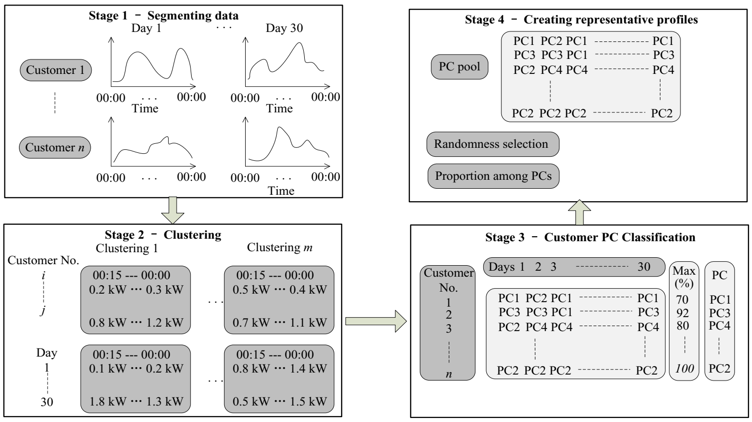

Fig. 2. Methodology for clustering and producing the representative demand profiles using smart metering data

4. Modelling Local Renewable Generation Resources

4.1. PV systems, and combined heat and power (CHP) units

The PV generation profile is produced using the Centre for Renewable Energy Systems Technology (CREST) [7] tool. Due to the relatively small area of LV networks, for a given day, all PV systems are considered to have the same generation profile. The nominal capacity of the PV systems is randomly selected from a range of 2.0 to 3.5 kWp. Assume the number of PV systems installed in an LV network is n_1, the total PV generation is presented by

$$G_{\mathrm{PV},t} = \sum_{n=1}^{n_1} P_{n,t}^{\mathrm{PV}} \tag{1}$$

For the electricity output of CHP, a heat demand-driven model was adopted. The electricity generation peaks normally take place in the morning and evening, when heat demand is high. Assume the number of CHP units is n_2, and the total electricity output is the summation of outputs from all CHP units,

$$G_{\mathrm{CHP},t} = \sum_{n=1}^{n_2} P_{n,t}^{\mathrm{CHP}} \tag{2}$$

4.2. Distributed generation in a Microgrid

The total distributed generation is presented by

$$G_t = G_{\mathrm{PV},t} + G_{\mathrm{CHP},t} \tag{3}$$

5. Problem Formulation

5.1. P2P index

Distributed generation supports the energy balance in local areas. The load in a distribution system is divided into the gross system load, distributed generation and net load. The net load is the residual load and it is reduced as part of the system load is supplied by distributed generation. The peer-to-peer index is defined by the proportion of distributed generation to the gross system load,

$$I_{P2P,t} = \frac{G_t}{L_t} \tag{4}$$

where $I_{P2P,t}$ is the P2P index, L_t is the gross system load and G_t is the distributed generation.

5.2. Optimization formulation

In an LV network, to achieve demand and supply balance, a set of DERs that result in the daily index equal to one is desired. Therefore, the objective function is expressed by

$$Min \sum_{t=0}^{24} (I_{P2P,t} - 1)^2 \tag{5}$$

6. Case Study

6.1. Demand data and clustering results

The electricity demand data from smart metering installed at the newly-built Zero Energy Bill (ZEB) houses at Corby, Northamptonshire, UK [8] was used. Figure 3(a) shows a one-week demand profiles of 4 customers with a 15-minute resolution. The proposed clustering method was carried out and Figure 3(b) shows the centroid daily profiles of four clusters, and it was found the corresponding proportion of these clusters are 27.1, 25.4, 10.0, and 37.5%. Two representative demand profiles was produced by randomly selecting different number of clusters, and used for Case 1 and Case 2. In Case 1, 90, 30, 30, and 90 profiles are selected from clusters 1, 2, 3 and 4, and in Case 2, 120, 30, 0, and 90 profiles are selected from these four clusters. Both of the two cases represent an LV network with 240 residential customers.

6.2. Optimization results

6.2.1. Two deterministic case

The proposed linear-programming optimization was carried out to find an optimal number of PV systems and an optimal rating of the CHP unit to supply the network demand. The results were compared amongst only using PV systems, and then only CHP units, and finally combined technologies of PV and CHP units. Figure 4(a) depicts the optimal PV generation for Case 1. Figure 4(b) depicts the optimal electricity rating of CHP units for Case 1. Figure 4(c) presents optimal number of PV system and CHP rating for Case 1. For the PV only case, 78 PV systems were required and the average daily P2P index was 0.38. This index doubled when adopting CHP units with a required rating of 186.3 kW. The P2P index was further increased to 0.86 when using the combined technologies for this deterministic case.

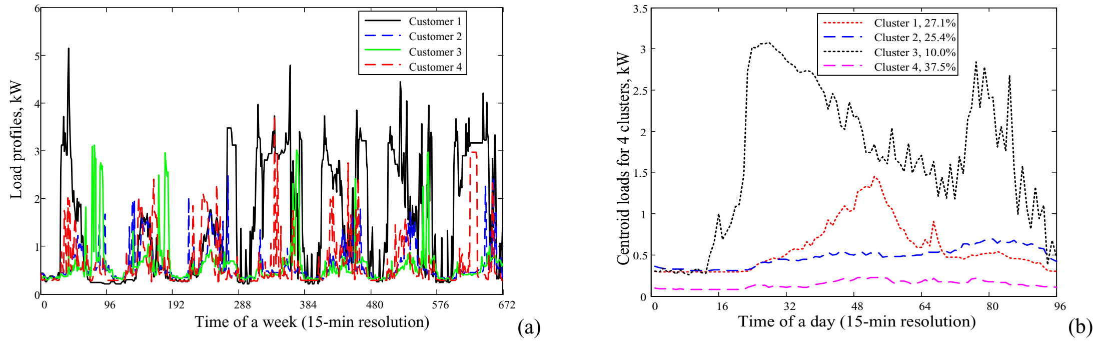

Fig. 3. (a) Examples of demand profiles of four customers from smart metering; (b) Centroid loads of 4 clusters

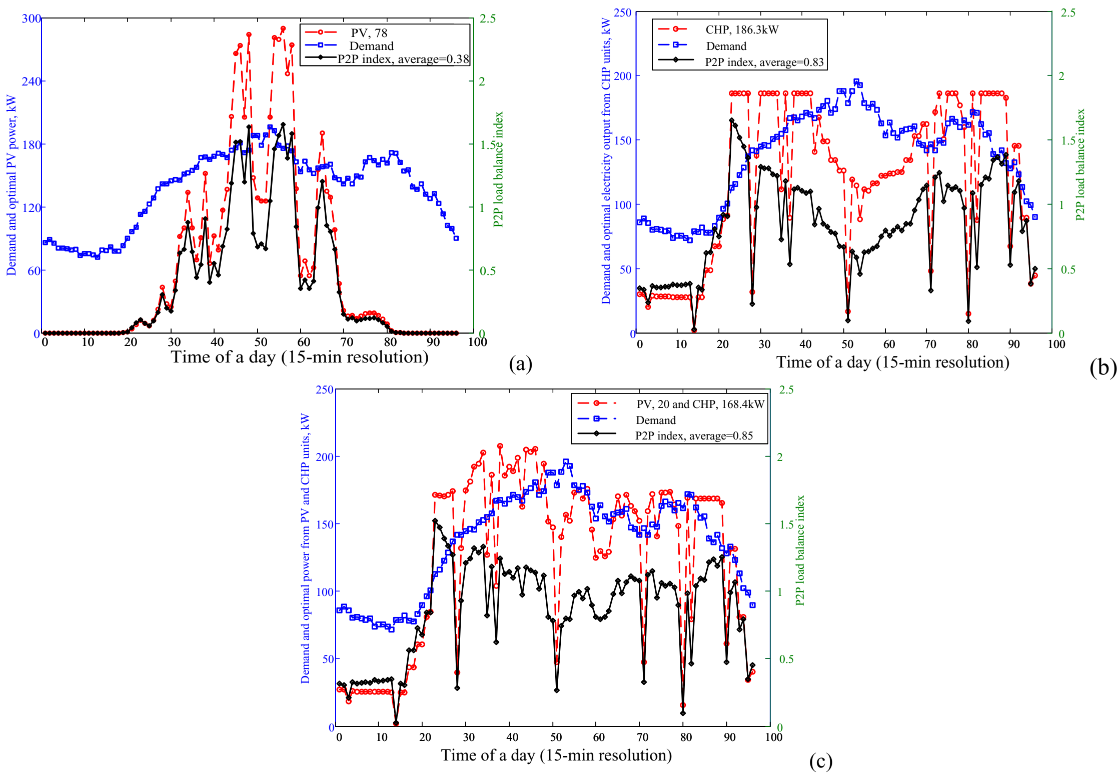

Fig. 4. Optimization results of Case 1: (a) PV only; (b) CHP units only; (c) PV and CHP units together

6.2.2. Monte Carlo analysis

Multiple simulations were carried out and each considered a daily network demand that is randomly selected from the cluster pools. The pool of PV generation was produced by CREST tool, and the CHP profiles also considered the randomness of the electricity generation. The average and deviation of the optimal number of PV system and CHP rating are presented in Figure 5. It is demonstrated that Case 2 required more proportion of PV systems, as Case 2 has more customers using electricity around mid-day.

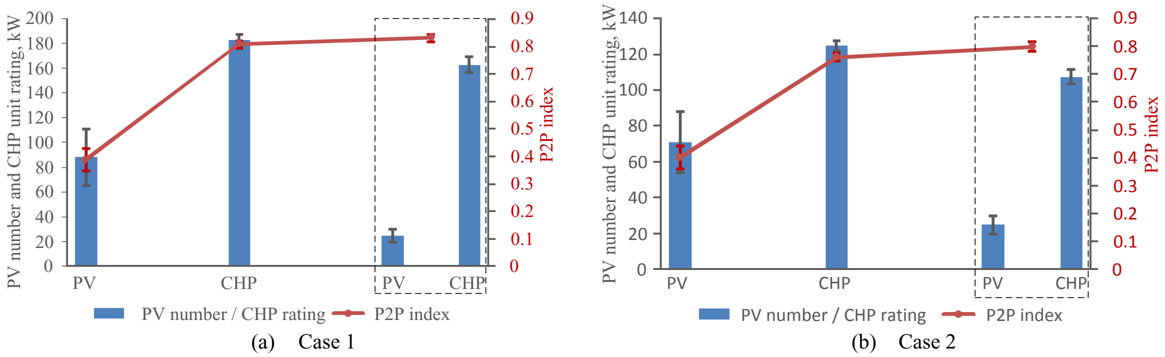

Fig. 5. Monte Carlo analysis: optimal PV number and CHP rating for PV only, CHP only and combined PV and CHP scenarios

7. Conclusions

To assess the feasibility of P2P energy trading, a P2P index considering local demand and generation balancing was developed. By clustering the smart metering data using the *k*-means method, customers' historical demand data was analyzed, and this helped to find the optimal DERs to balance the networks' demand. The methodology was verified by a case study considering an LV distribution networks with residential customers. This work provides network planners with guidelines of appropriate shares of DERs for better constructing their networks, and facilitates a P2P energy trading market paradigm.

8. Copyright

9. Acknowledgements

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